New material of the Early Pleistocene mammalian fauna from Chutoulang, Chifeng, eastern Nei Mongol, China and binary faunal similarity analyses postprint

Authors: DONG Wei, ZHANG Li-Min, LIU Wen-Hui, DONG Wei

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Abstract

New specimens from a new locality at Chutoulang in eastern Nei Mongol were identifed as Canis chihliensis, Coelodonta nihowanensis, Hipparion (Proboscidipparion) sinense,Equus sanmeniensis, Sus lydekkeri, Muntiacus cf. M. lacustris, Axis shansius, Eucladoceros boulei, Spirocerus cf. S. wongi and Bison palaeosinensis. They enriched the mammalian fauna of Chutoulang to 30 taxa together with the material from Dongliang, Dongcun Beigou and Dongcun Nangou localities. The mammalian fossils from these four localities are all from the same horizon and can be regarded as the same fauna, i.e. Chutoulang fauna. The composition of Chutoulang fauna is the closest to that of Nihewan (s.s.) by binary faunal similarity coeffcients. The age of Chutoulang fauna is between those of Nihewan (s.s.) and Juyuandong at Liucheng according to Brainerd-Robinson' s sequence, extinction rates and antiquity coeffcients. The numerical age of Chutoulang fauna is estimated between 1.4–1.6 Ma based on those of compared faunas. Carnivora are the most numerous in Chutoulang fauna with 11 taxa, but mostly the small sized ones.Perissodactyla and Artiodactyla make about half of the fauna. They are mostly large sized forms. The presence of numerous browsers or forest dwellers implies the existence of forest or woodland in Chutoulang area during that period. The presence of grazers and openland dwellers indicates the existence of larger area of grassland or steppes than that of woodland or forests. Most members of Chutoulang fauna are temperate habitat dwellers with a few cold-prone forms such as Ochotona and Coelodonta. The climate in Chutoulang area in the Early Pleistocene was thus similar to that of today. Chutoulang fauna is the most northeastern Early Pleistocene fauna in China and it can be recommended as a type site of the Early Pleistocene mammalian fauna in northeastern China.

Full Text

Preamble

New Material of the Early Pleistocene Mammalian Fauna from Chutoulang, Chifeng, Eastern Nei Mongol, China and Binary Faunal Similarity Analyses

DONG Wei[1], ZHANG Li-Min[1], LIU Wen-Hui[1,2]
(1 Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, dongwei@ivpp.ac.cn)
(2 University of Chinese Academy of Sciences, Beijing 100039)

Abstract
New specimens from a new locality at Chutoulang in eastern Nei Mongol were identified as *Canis chihliensis*, *Coelodonta nihowanensis*, *Hipparion (Proboscidipparion) sinense*, *Equus sanmeniensis*, *Sus lydekkeri*, *Muntiacus* cf. *M. lacustris*, *Axis shansius*, *Eucladoceros boulei*, *Spirocerus* cf. *S. wongi* and *Bison palaeosinensis*. Together with material from the Dongliang, Dongcun Beigou and Dongcun Nangou localities, these specimens enrich the mammalian fauna of Chutoulang to 30 taxa. The mammalian fossils from these four localities all derive from the same horizon and can be regarded as a single fauna, i.e., the Chutoulang fauna. Based on binary faunal similarity coefficients, the composition of the Chutoulang fauna is closest to that of Nihewan (s.s.). According to Brainerd-Robinson' s sequence, extinction rates and antiquity coefficients, the age of the Chutoulang fauna falls between those of Nihewan (s.s.) and Juyuandong at Liucheng. The numerical age of the Chutoulang fauna is estimated at 1.4–1.6 Ma based on comparisons with dated faunas. Carnivora are the most numerous order in the Chutoulang fauna with 11 taxa, but most are small-sized forms. Perissodactyla and Artiodactyla together comprise about half of the fauna, and are mostly large-sized forms. The presence of numerous browsers or forest dwellers implies the existence of forest or woodland in the Chutoulang area during that period, while the presence of grazers and openland dwellers indicates that grasslands or steppes covered a larger area than woodlands or forests. Most members of the Chutoulang fauna are temperate habitat dwellers, with a few cold-adapted forms such as *Ochotona* and *Coelodonta*. The climate in the Chutoulang area during the Early Pleistocene was thus similar to that of today. The Chutoulang fauna is the most northeastern Early Pleistocene fauna in China and can be recommended as a type site for the Early Pleistocene mammalian fauna of northeastern China.

Keywords: Chutoulang, Chifeng, Nei Mongol; Early Pleistocene; mammalian fauna; binary similarity coefficient

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1 Introduction

Chutoulang is a small town (42°18 28.68 -42°19 16.78 N, 118°37 20.31 - 118°38 23.87 E) located approximately 22.5 km west (bearing 287°) of Chifeng City and 329.6 km northeast (bearing 34.35°) of Beijing. Administratively, it belongs to Chifeng Municipality of the Nei Mongol Autonomous Region, and was formerly part of Jehol Province (1928–1955) and Liaoning Province (1969–1979). During a 1986 field investigation around Dongliang village in Chutoulang, Zhang and his students discovered a fossil assemblage in fluvial-lacustrine deposits (Zhang, 1989). Follow-up excavations yielded approximately 18 mammalian taxa: *Ochotona* sp., *Marmota* sp., *Microtus* sp., *Vulpes* sp., *Meles leucurus*, *Meles* sp., *Panthera* sp., *Poguma* sp., *Hipparion* sp., *Proboscidipparion sinense*, *Equus sanmeniensis*, *Coelodonta antiquitatis*, *Axis rugosus*, *Cervus (Sika) grayi*, Cervinae gen. et sp. indet., *Procapreolus* sp., *Gazella sinensis*, and *Bison palaeosinensis*. This fossil assemblage was considered contemporaneous with the Xihoudu Paleolithic site and the Xicun fauna of Shanxi Province, and the fossil-bearing deposits were designated the Dongliang Formation (Zhang, 1989).

Excavations continued from 1986 to 1987, extending from Dongliang to Beigou and Nangou around Dongcun (Dong Village) in Chutoulang. Mammalian fossils collected from these two localities included 21 taxa: *Procynocephalus wimani*, *Canis variabilis*, *C. chihliensis* var. *palmidens*, *Nyctereutes sinensis*, *Ursus* sp., *Hyaena licenti*, *Panthera tigris*, *Acinonyx* sp., *Hipparion* sp., *H. (Proboscidipparion) sinense*, *Equus sanmeniensis*, *Nestoritherium* sp., *Rhinoceros* cf. *R. sinensis*, *Coelodonta antiquitatis*, *Sus lydekkeri*, *Gazella sinensis*, *Gazella* cf. *G. subgutturosa*, *Cervus* sp., *Bison palaeosinensis*, *Bos* sp., and *Paracamelus gigas* (You and Zhang, 1989).

The presence of "dragon bones" (mammalian fossils) at Chutoulang attracted not only paleontologists but also illegal fossil hunters. Illegal digging increased in frequency in recent years, prompting the local government to implement a protection project under the supervision of the Department of Land Resources of the Nei Mongol Autonomous Region to recover fossils before they could be sold on the black market. An authorized paleontological excavation was conducted in 2012 at the Xiaonanshan fossil locality in Chutoulang, yielding numerous new mammalian fossil specimens that form the basis of the present study. Specimens prefixed with CTL (Chutoulang) are housed in the Division of Land Resources of Songshan District, Chifeng City, Nei Mongol.

The Xiaonanshan fossil locality is situated 2.13 km northeast (bearing 54.13°) of Chutoulang, with coordinates ranging from 42°19 43.30 N to 42°19 46.66 N and from 118°39 07.01 E to 118°39 16.06 E, at an average altitude of 688 m. Fossils were recovered from a main layer of reddish and brownish clay or sandy clay, 5-7 m thick, with an interbedded layer of grayish silt, particularly within or near this silt layer. This main layer corresponds to the lower part of the Dongliang Formation that yields mammalian fossils (Zhang, 1989; You and Zhang, 1989).

According to Zhang (1989), the Dongliang fossil locality is likely located near present-day Shahudong Village, approximately 1 km south of the Xiaonanshan locality. The Beigou locality of You and Zhang (1989) lies north of present-day Dahedong Village, probably about 1 km north of Xiaonanshan based on information from local residents who participated in Zhang's (1989) excavations. The Nangou locality of You and Zhang (1989) is very close to the present-day Xiaonanshan locality. All fossils were collected from the lower part of a series of fluvial-lacustrine deposits designated as the Dongliang Formation by Zhang (1989).

2 Systematic Paleontology

Mammalia Linnaeus, 1758
Carnivora Bowdich, 1821
Caniformia Kretzoi, 1943
Canidae Fischer de Waldheim, 1817
Caninae Fischer de Waldheim, 1817
Canis Linnaeus, 1758
Canis chihliensis Zdansky, 1924 (Fig. 1 [Figure 1: see original paper])

Material: A left M1 (CTL23-2, crown length: 12.92 mm, width: 16.09 mm, height: 8.56 mm) and a broken left m1 (CTL46-6, length: >14.9 mm, width: 9.1 mm, height: 14.2 mm).

Remarks: Both the M1 and broken m1 show no wear facets and therefore represent relatively young individuals. The specimens are morphologically similar to those of *Canis chihliensis* from Xiashagou described by Teilhard de Chardin and Piveteau (1930) and closely resemble material from Shanshenmiaozui (Tong et al., 2012). They are metrically smaller than *C. chihliensis* from Xiashagou and Shanshenmiaozui but similar to *C. chihliensis* var. *parmidens* and *C. chihliensis* var. *minor* from Xiashagou (Teilhard de Chardin and Piveteau, 1930). The taxonomic status of *C. chihliensis* var. *parmidens* is controversial (Qiu et al., 2004), and *C. chihliensis* var. *minor* has been included within the late Neogene form *Eucyon* (Tedford and Qiu, 1996). The present specimens indicate that a relatively small canid similar to *C. chihliensis* with some archaic features existed at Xiaonanshan.

Canis chihliensis is absent at the Dongliang locality (Zhang, 1989) but present at the Dongcun localities as *C. chihliensis* var. *parmidens* (You and Zhang,

1989). The latter is here considered as *C. chihliensis* together with the material from Xiaonanshan.

Perissodactyla Owen, 1848
Rhinocerotoidea Gill, 1872
Rhinocerotidae Gray, 1821
Dicerorhininae Simpson, 1945
Coelodonta Bronn, 1831
Coelodonta nihowanensis Kahlke, 1969 (Fig. 2 [Figure 2: see original paper])

Material: A right DP4 (CTL19-1). Length: 49.57 mm, width: 44.90 mm, height: 39.53 mm.

Remarks: The crown height of the DP4 is moderate, and the occlusal outline of the crown is nearly triangular. The enamel layer is well preserved, and the cavity inside the enamel layer is very large. The ectoloph is undulated, the anterior fossette is large and connected with a wide middle fossette, while the posterior fossette is short and wide.

The Chutoulang specimen is similar to *Rhinoceros* cf. *R. tichorhinus* described by Teilhard de Chardin and Piveteau (1930), which was later defined as *Coelodonta nihowanensis* by Kahlke (1969). It is also close to *C. nihowanensis* from Longdan (Qiu et al., 2004) both morphologically and metrically.

The left M1, right M1, left p4 and right m2 of "Coelodonta antiquitatis" from the Dongliang locality described by Zhang (1989) are evidently smaller and more archaic than those of the Late Pleistocene *C. antiquitatis* (Zhang, 1989) and actually represent *C. nihowanensis*. The "C. antiquitatis" from the Dongcun localities mentioned by You and Zhang (1989) is the same case.

Perissodactyla Owen, 1848
Equidae Gray, 1821
Hipparion de Christol, 1832
Hipparion (Proboscidipparion) Sefve, 1927
Hipparion (Proboscidipparion) sinense Sefve, 1927 (Fig. 3 [Figure 3: see original paper])

Material: A left third metacarpal with reduced and broken second and fourth metacarpals (CTL33-1), and a left third proximal phalanx (CTL26).

Remarks: The left metacarpal III (CTL33-1) is well preserved with only a few minor fractures (Fig. 3A–C). The lateral and medial sides of the distal part of metacarpal III show facets for contact with metacarpals II and IV, evidence typical of hipparionines, although metacarpals II and IV are preserved only as two-thirds of their proximal portions, with the distal thirds broken off (Fig. 3A).

The proximodistal length of metacarpal III (CTL33-1) measures 267.6 mm; the anteroposterior and mediolateral diameters at the midpoint of metacarpal III are 32.6 mm and 35.8 mm, respectively. The mediolateral and anteroposterior diameters of the proximal facet for the carpals measure 51.5 mm and 40.0 mm,

respectively, while those of the distal facet for the proximal phalanx III are 44.9 mm and 36.9 mm, respectively. The metacarpals (CTL33-1) are very similar to those of *Hipparion (Proboscidipparion) sinense* from the Yushe Basin (Qiu et al., 1987) and Longdan (Qiu et al., 2004).

The left third proximal phalanx (CTL26) is stout, with moderately expanded proximal and distal condyles (Fig. 3D–F). Its length is 79.2 mm; its anteroposterior diameter is 37.3 mm at the proximal end, 30.0 mm in the middle, and 24.5 mm at the distal end; its mediolateral diameter is 40.3 mm at the proximal end and 43.3 mm at the distal end.

Some isolated cheek teeth with isolated protocones in upper cheek teeth from the Dongliang locality were assigned to *Hipparion (Proboscidipparion) sinense* (Zhang, 1989). The species was also reported from the Dongcun localities (You and Zhang, 1989).

Equus Linnaeus, 1758
Equus sanmeniensis Teilhard de Chardin & Piveteau, 1930 (Fig. 4 [Figure 4: see original paper]; Table 1)

Material: A right mandibular fragment with p2–m3 (CTL42-1), a left mandibular fragment with p3–m3 (CTL42-2), an anterior part of a mandible with all incisors and some cheek teeth (CTL39-1-1), a mandibular symphysis with all incisors (TCL34-2), a right mandibular fragment with m2–3 (CTL30-2), a left M3 (CTL18-1), a left p3 (CTL12-3), a left p4 (CTL14), a right m1 (CTL12-2), a left m2 (CTL12-5), a left m3 (CTL12-1), a left and a right talus (CTL34-1, CTL07-1), and a left proximal third phalanx (TCL33-5).

Remarks: Specimens of this species are the most numerous among the Xiaonanshan material. The protocone of M3 (CTL18-1) is long and nearly triangular in occlusal view and connected to the protoconule. The tooth is covered by a cement layer, especially on the lingual side. There are five incomplete lower dentitions. The double-knot pattern of the lower cheek teeth is stenonid.

The Xiaonanshan specimens are morphologically close to those of *Equus sanmeniensis*—for example, the mesostyle of M3 is simple and not folded, its protocone is long, and the double-knot pattern in lower cheek teeth is stenonid, with the ectoflexid extending into the neck of the double-knots. The dimensions of the Xiaonanshan specimens are relatively large and close to those of *E. sanmeniensis* from Xiashagou of Nihewan (Teilhard de Chardin and Piveteau, 1930), *E. huanghoensis* from Luping (Chow and Liu, 1959) and Tuozidong (Dong and Fang, 2005), and *E. eisenmannae* from Longdan (Qiu et al., 2004), but are evidently larger than those of *E. przewalskii* and *E. dalianensis* from Longgushan (Zhou et al., 1985).

E. sanmeniensis was reported from the Dongliang locality (Zhang, 1989) as well as the Dongcun localities (You and Zhang, 1989).

Artiodactyla Owen, 1848
Suoidae Cope, 1887

Suidae Gray, 1821
Suinae Zittel, 1893
Sus Linnaeus, 1758
Sus lydekkeri Zdansky, 1928 (Fig. 5 [Figure 5: see original paper]; Table 2)

Material: A right juvenile maxillary fragment with DP2–4 (CTL10), a left mandibular fragment with p2–3 (CTL11), and a left juvenile mandibular fragment with p2–3 and dp4 (CTL16).

Remarks: The suid material is fragmentary, consisting only of juvenile maxillary and mandibular fragments. The teeth are typically suid in form. DP4 and dp4 are fully molarized (Fig. 5A–B, F). The p2 and p3 are composed of a main cusp and a few accessory cusplets (Fig. 5C–F). The available morphological, metric, and stratigraphic data for the material are consistent with those of *Sus lydekkeri*.

Sus lydekkeri was not reported from the Dongliang locality (Zhang, 1989) but was present at the Dongcun localities (You and Zhang, 1989).

Ruminantia Scopoli, 1777
Pecora Flower, 1883
Cervoidea Simpson, 1931
Cervidae Gray, 1821
Muntiacinae Pocock, 1923 (=Cervulinae Sclater, 1870)
Muntiacus Rafinesque, 1815 (=Cervulus Blainville, 1816)
Muntiacus cf. *M. lacustris* Teilhard de Chardin & Trassaert, 1937 (Fig. 6A-B [Figure 6: see original paper]; Table 3)

Material: A right maxillary fragment with M2–3 (CTL22-1), and a left mandibular fragment with m2–3 (CTL04-2).

Remarks: The molars are relatively small (Table 3) and typically selenodont with moderate crown height. Accessory elements such as the entostyle (basal pillar) and enamel folds on the crests of the main cusps are present in upper molars (Fig. 6A), while precingulid and ectostylid (basal pillar) are present in lower molars (Fig. 6B). The specimens are evidently larger than those of moschids and are morphometrically muntjac-like. The Xiaonanshan specimens fall within the metric range of *Muntiacus lacustris* from Early Pleistocene deposits of the Gigantopithecus Cave at Liucheng (Han, 1987) and Dadong (=Sanhe Cave) at Chongzuo (Dong et al., 2011).

Unfortunately, no antler material is available at Xiaonanshan.

Muntjacs were not reported from the Dongliang locality (Zhang, 1989) or the Dongcun localities (You and Zhang, 1989). However, a medium-sized cervid, *Procapreolus* sp., represented by a mandibular fragment with m2–3, was reported from Dongliang (Zhang, 1989). The cervids from the Dongcun localities consist only of a *Cervus* sp. (You and Zhang, 1989). The Xiaonanshan specimens are slightly larger than those of *Procapreolus jinensis* from the Late Miocene deposits of the Yushe Basin (Dong and Ye, 1996) and those of extant *Capreolus*

capreolus housed at the Laboratoire d' Anatomie Comparée de Paris (e.g., 1948-46, Sl-1erE-38; 1951-228, Sl-RC-t369).

The *Procapreolus* sp. from Dongliang reported by Zhang (1989) is therefore more likely a muntjac, similar to that from Xiaonanshan.

Cervinae Baird, 1857
Eucladoceros Falconer, 1868
Eucladoceros boulei Teilhard de Chardin & Piveteau, 1930 (Fig. 6C–D [Figure 6: see original paper]; Table 3)

Material: A left M3 (CTL08), and a right mandibular fragment with m2–3 (CTL35-1).

Remarks: The M3 is composed of four selenodont main cusps without evident accessory elements such as enamel folds on the crests of the lingual main cusps or cingula. The m2 and m3 are also composed of selenodont main cusps with weak precingulid and ectocingulid, as well as a developed ectostylid (basal pillar).

The specimens represent a relatively large cervid (see Table 3 for measurements). The only Early Pleistocene cervid of similar size is *Eucladoceros boulei* from the Nihewan Basin (Teilhard de Chardin and Piveteau, 1930), and the Xiaonanshan specimens can also be assigned to this species, although no antler material is available. *Eucladoceros boulei* was not reported from either the Dongliang (Zhang, 1989) or Dongcun (You and Zhang, 1989) localities, making this its first discovery in the Chutoulang area.

Axis Smith, 1827
Axis shansius Teilhard de Chardin & Trassaert, 1937 (Fig. 6E–G [Figure 6: see original paper]; Table 3)

Material: A maxillary fragment with both left and right P3–M3 (CTL05-1), a right maxillary fragment with M2–3 (CTL12-10), a left mandibular fragment with p4–m3 (CTL42-6), a left calcaneus (CTL02-2), and a left talus (CTL07-2).

Remarks: The P3 is composed of two fused lobes with an evident entoflexus, while P4 consists of a single lobe without entoflexus. The M1–3 are all composed of four selenodont main cusps with evident spur, entocingulum, and entostyle (basal pillar); other accessory elements are absent. Precingulid and ectostylid (basal pillar) are evident in all lower molars. The first lobe is longer than the second in m1 and m2, but they are nearly equal in m3. The third lobe of m3 is relatively small. The Xiaonanshan specimens are evidently smaller than those of *Elaphurus bifurcatus*, *Eucladoceros boulei*, and *Cervus (Rusa) elegans* from Nihewan (Teilhard de Chardin and Piveteau, 1930) but close to those of *Axis shansius* from the Yushe Basin (Teilhard de Chardin and Trassaert, 1937) and Dajushan (Dong, 2006).

The calcaneus body (CTL02-2) is relatively short, with a length of 66.52 mm and an anteroposterior diameter of 40.89 mm; the anteroposterior diameter of the calcaneal tuber measures 34.8 mm. The sustentaculum tali and coracoid

process are developed. In the talus (CTL07-2), the proximal trochlea is more developed than the distal trochlea; the transverse and anteroposterior diameters of the proximal trochlea are 46.89 mm and 35.67 mm, respectively, while those of the distal trochlea are 44.28 mm and 34.05 mm, respectively.

The fragmentary material reported as "Cervus (Sika) grayi" from Dongliang (Zhang, 1989) can also be assigned to *Axis shansius*, as *Cervus (Sika) grayi* is mostly present in the Middle Pleistocene and the Dongliang specimens are morphologically close to those of *Axis shansius* from Yushe.

Bovidae Gray, 1821
Antilopinae Baird, 1857
Spirocerus Boule & Teilhard de Chardin, 1928
Spirocerus cf. *S. wongi* Teilhard de Chardin & Piveteau, 1930 (Fig. 7A–B [Figure 7: see original paper]; Table 3)

Material: A left mandibular fragment with m2–m3 (CTL18-2).

Remarks: The m2–3 are high-crowned without accessory elements such as cingula or ectostylid (basal pillar). The lingual main cusps are higher than those on the buccal side, and the crests of the main cusps are sharp. These characters indicate an antelope. The specimens are morphologically close to those of *Spirocerus wongi* from Nihewan (Teilhard de Chardin and Piveteau, 1930), but the dimensions are slightly smaller.

Gazella sinensis was reported from the Dongliang locality (Zhang, 1989) and from the Dongcun localities together with *Gazella* cf. *G. subgutturosa* (You and Zhang, 1989). Both gazelles are evidently smaller than *Spirocerus wongi*.

Bovinae Gray, 1821
Bison Smith, 1827
Bison palaeosinensis Teilhard de Chardin & Piveteau, 1930 (Fig. 7C–D [Figure 7: see original paper]; Table 3)

Material: A right mandibular fragment with m1–2 (CTL27).

Remarks: Bovine material is very limited at the Xiaonanshan locality, but specimen CTL27 is clearly bovine, as evidenced by very high crowns, developed ectostylids (basal pillar), and enamel folds on the main cusp crests. A primitive bovine, *Bison palaeosinensis*, was reported from the Dongliang locality (Zhang, 1989), represented by a complete horn core with partial frontal, four isolated upper molars, and a pair of mandibles with cheek dentitions. It was also reported from the Dongcun localities (You and Zhang, 1989). The Xiaonanshan specimen is therefore very likely *Bison palaeosinensis*, although frontal appendages are absent.

3 Fauna Analyses

All specimens collected during the 2012 excavation can be identified as ten taxa as mentioned above, among which *Muntiacus* cf. *M. lacustris*, *Eucladoceros*

boulei, and *Spirocerus* cf. *S. wongi* are newly identified taxa in the Chutoulang area. Together with those from the Dongliang locality (Zhang, 1989) and Dongcun localities (You and Zhang, 1989), the identified mammalian taxa from the Chutoulang area total 30: *Procynocephalus wimani*; *Ochotona* sp.; *Marmota* sp.; *Microtus* sp.; *Vulpes* sp.; *Canis variabilis*; *Canis chihliensis*; *Nyctereutes sinensis*; *Meles meles* (=leucurus); *Meles* sp.; *Poguma* sp.; *Ursus* sp.; *Pachycrocuta brevirostris licenti* (=Hyaena licenti); *Panthera tigris*; *Acinonyx* sp.; *Rhinoceros* cf. *R. sinensis*; *Coelodonta nihowanensis*; *Hipparion (Proboscidipparion) sinense*; *Equus sanmeniensis*; *Nestoritherium* sp.; *Sus lydekkeri*; *Paracamelus gigas*; *Muntiacus* cf. *M. lacustris*; *Axis shansius*; *A. rugosus*; *Eucladoceros boulei*; *Spirocerus* cf. *S. wongi*; *Gazella sinensis*; *G.* cf. *G. subgutturosa*; *Bison palaeosinensis*.

These fossils were all recovered from the same horizon—a layer of reddish and brownish clay or sandy clay with an interbedded layer of grayish silt—and the fossil localities are close to each other. All taxa can therefore be regarded as representing a single fauna, i.e., the Chutoulang fauna.

Material and Methods

To determine the compositional, zoogeographic, and biochronological position of the Chutoulang fauna, we selected for comparison several representative Early Pleistocene faunas from different regions of China with more than 30 taxa: Nihewan (s.s.) (Teilhard de Chardin and Piveteau, 1930; Qiu, 2000; Tong et al., 2011) in northern China; Gongwangling (Hu and Qi, 1978) and Longdan (Qiu et al., 2004) in northwestern China; Renzidong (Jin and Liu, 2009) in eastern China; Longgupo (Huang and Fang, 1991) and Longgudong (Zheng, 2004) in central China; Juyuandong (Pei, 1987; Han, 1987) and Dadong (Jin et al., 2009) in southern China. A French fauna from upper Saint-Vallier (LD3) (Guérin et al., 2004) was also selected as a classic European Villafranchian fauna for comparison.

Because the presence or absence of a taxon in a fauna is a binary variable, matching coefficients between binary variables can be used to evaluate the similarity of two faunas (Chen, 1983, 2005). If taxon k is either present or absent in both fauna i and fauna j, we define the matching coefficient of taxon k (Rijk) in the paired faunas as Rijk = 1. If taxon k is present in only one of the two faunas, we define the matching coefficient of taxon k (Rijk) as Rijk = 0. In cases where a taxon can only be identified at the genus or family level, the matching coefficient is defined as Rijk = 0.5. The binary faunal similarity coefficient of two compared faunas (Rij) is defined as the double sum of the matching coefficients of all taxa in the paired faunas:

$$\text{Rij} = 2 \times \quad \text{Rijk}$$

All extinct taxa, including regionally extinct ones, from all compared faunas were considered as a presumed archaic fauna, and extant taxa as a presumed modern fauna. All compared faunas, as well as the presumed archaic and modern faunas, were compared pairwise to calculate all binary faunal similarity

coefficients. These coefficients were then sequenced by antiquity coefficients, defined as the binary faunal similarity coefficient between a fauna and the presumed archaic fauna (Dong et al., 2013; Dong, 2016), and they were also ranked according to Brainerd-Robinson' s (B.-R.) rule (Chen, 2005) in ascending order from youngest to oldest (Table 4). The fauna extinction rate is classically defined as the percentage of extinct taxa relative to the total number of taxa in the fauna. Because each fauna may be sorted into different positions by different criteria, we define a B.-R. index for each fauna in the B.-R. sequence as its sequence position number (Table 5). We define an extinction index of a fauna k as Exk, the maximal extinction rate of the compared faunas as Emax, the minimal extinction rate as Emin, the number of compared faunas as n, and the extinction rate of fauna k as Ek. The extinction index Exk of fauna k can then be calculated by the following formula:

$$\text{Exk} = (\text{Ek} - \text{Emin}) \div [(\text{Emax} - \text{Emin}) \div (\text{n} - 1)] + 1$$

The antiquity index of a fauna is defined and calculated in the same way, substituting the extinction rates with the antiquity coefficients of the faunas (Table 5). We then sum the three indices of a fauna in each sequence as its combined index and sort the faunas in ascending order according to their combined indices.

Results

All binary faunal similarity coefficients of the compared faunas are listed in Table 4 . In terms of binary faunal similarity coefficients (Table 4), the fauna most similar to Chutoulang is Nihewan (s.s.) (541), followed by those of Longdan and Dadong (527), Juyuandong and Gongwangling (521), Saint-Vallier (497), Longgudong (447), Renzidong (443), and finally Longgupo (437). However, in terms of sequenced binary similarity coefficients according to Brainerd-Robinson' s rule (Table 4), the faunas most similar to Chutoulang are those of Longdan and Juyuandong, followed by those of Nihewan (s.s.) and Dadong, Saint-Vallier and Longgudong, Gongwangling and Longgupo, and finally Renzidong.

As listed in Table 5 , the Chutoulang fauna is the fifth youngest among all compared faunas according to Brainerd-Robinson' s rule. It is the fourth youngest fauna among all compared faunas after those of Gongwangling, Dadong, and Juyuandong according to faunal antiquity coefficients. It is the fourth oldest fauna among all compared faunas after those of Longdan, Saint-Vallier, and Nihewan (s.s.) according to extinction rates. It is also the fifth youngest fauna among all compared faunas after those of Gongwangling, Dadong, Longgudong, and Juyuandong according to comprehensive criteria.

4 Discussion and Conclusion

Based on binary faunal similarity coefficients (Table 4), the relationship between the Chutoulang fauna and that of Nihewan (s.s.) is the closest, which accords with their zoogeographic context. However, in terms of sequenced binary similarity coefficients according to B.-R.' s rule (Table 4), the faunas

most similar to Chutoulang are those of Longdan and Juyuandong. The close relationship between Chutoulang and Longdan is also evident in binary faunal similarity coefficients, and both faunas belong to the Palearctic region. The similarity with Juyuandong of the Oriental region can only be interpreted in terms of their biochronological context (Table 5). Although the Saint-Vallier fauna is geographically the most distant among all compared faunas, it is not the least similar to Chutoulang either in terms of binary faunal similarity coefficients or according to B.-R. sequence. This may indicate that the Chutoulang fauna and that of Saint-Vallier belonged to the same zoogeographic region (Palearctic) and a similar biochronological period.

The age of the Chutoulang fauna was previously considered equivalent to that of Nihewan (s.s.) (Zhang, 1989; You and Zhang, 1989). Biochronologically, the Chutoulang fauna is closest to those of Longdan and Juyuandong according to B.-R. sequence, closest to those of Longgudong and Juyuandong in terms of antiquity coefficients, closest to those of Renzidong and Nihewan (s.s.) in terms of extinction rates, and falls between those of Nihewan and Juyuandong according to combined evaluation criteria (Table 5).

The combined correlations also indicate that the faunas of Nihewan (s.s.), Longgupo, Saint-Vallier, and Longdan are biochronologically very close to each other, with very small differences between their combined indices. Indeed, the Nihewan (s.s.) fauna resides in the Matuyama reverse chron between the pre-Reunion Matuyama and post-Olduvai Matuyama chrons, with an estimated age of ca. 2.2–1.7 Ma (Liu et al., 2012). The age of the Longgupo fauna from the middle zone of the cave deposits was estimated at 1.12 Ma by ESR and 1.96 Ma by paleomagnetism (Huang et al., 1995). The Saint-Vallier fauna, one of the standard middle Villafranchian faunas equivalent to biozone MNQ17, was correlated to Chron C2r between 1.95 and 2.58 Ma (Sen, 2004) and is generally accepted as about 2 Ma (Guérin et al., 2004). The Longdan fauna was dated by paleomagnetism to 2.55–2.16 Ma and is generally regarded as 2.2 Ma (Qiu et al., 2004). The Juyuandong fauna has not yet been dated by paleomagnetic, ESR, or other physical or chemical methods. The Longgudong fauna was dated paleomagnetically to 2.42–2.15 Ma (Zheng, 2004), but this has been questioned and Longgudong fauna is considered younger than that of Longgupo (Jin et al., 2009). The Dadong fauna was also dated by paleomagnetism to 1.2 Ma (Jin et al., 2009). The numerical age of the Chutoulang fauna should therefore be younger than 1.8 Ma and older than 1.2 Ma, likely about 1.4–1.6 Ma.

The newly identified material from the Xiaonanshan locality of Chutoulang totals ten taxa: *Canis chihliensis*, *Coelodonta nihowanensis*, *Hipparion (Proboscidipparion) sinense*, *Equus sanmeniensis*, *Sus lydekkeri*, *Muntiacus* cf. *M. lacustris*, *Axis shansius*, *Eucladoceros boulei*, *Spirocerus* cf. *S. wongi*, and *Bison palaeosinensis*.

Xiaonanshan is the fourth fossil locality in Chutoulang, in addition to the previously known Dongliang, Dongcun Beigou, and Dongcun Nangou localities. The mammalian fossils from these four localities all derive from the same horizon

and can be regarded as a single fauna, i.e., the Chutoulang fauna. Carnivora are the most numerous order in the Chutoulang fauna with 11 taxa, but most are small-sized. Perissodactyla and Artiodactyla together comprise about half of the fauna and are mostly large-sized forms. The presence of numerous browsers or forest dwellers such as *Procynocephalus wimani*, *Poguma* sp., *Ursus* sp., *Panthera tigris*, *Rhinoceros* cf. *R. sinensis*, *Nestoritherium* sp., *Sus lydekkeri*, *Muntiacus* cf. *M. lacustris*, *Axis shansius*, *A. rugosus*, and *Eucladoceros boulei* implies the existence of forest or woodland in the Chutoulang area. The presence of grazers and openland dwellers such as *Ochotona* sp., *Marmota* sp., *Microtus* sp., *Vulpes* sp., *Canis variabilis*, *C. chihliensis*, *Nyctereutes sinensis*, *Pachycrocuta brevirostris licenti* (=Hyaena licenti), *Acinonyx* sp., *Coelodonta nihowanensis*, *Hipparion (Proboscidipparion) sinense*, *Equus sanmeniensis*, *Spirocerus* cf. *S. wongi*, *Gazella sinensis*, *G.* cf. *G. subgutturosa*, and *Bison palaeosinensis* indicates that grasslands or steppes covered a larger area than woodlands or forests. Most members of the Chutoulang fauna are temperate habitat dwellers, with only a few cold-adapted forms such as *Ochotona* and *Coelodonta*. The climate in the Chutoulang area during the Early Pleistocene was thus similar to that of today.

The Chutoulang fauna is the most northeastern Early Pleistocene mammalian fauna in China and can be recommended as a type site for the Early Pleistocene mammalian fauna of northeastern China.

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Note: Figure translations are in progress. See original paper for figures.